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MSFC HOT AIR COLLECTORS -- FINAL REPORT

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MSFC HOT AIR COLLECTOR – FINAL REPORT

INTRODUCTION

The final report on the MSFC hot air collector consists of the description of the collector, history of development, a history of the materials development and a program summary. The appendix and References 1 and 2 present all testing performed with the exception of the Building 4638, which will have a report after publication of this document. However, some of the Building 4638 test results are included in this report.

DESCRIPTION OF MSFC HOT AIR COLLECTOR

It is well known that one of the major obstacles in widespread application of solar energy is the initial cost of the system required for the utilization of this energy. The major portion of the solar energy system cost is the collector. Since the collector is the "heart" of the system and the most costly subsystem, reducing the cost of producing collectors in large quantities is a major goal. This solar collector is designed for economy and simplicity. In summary, the purpose of this invention is to heat air and/or water cheaply and efficiently through the use of solar energy.

This hot air solar collector (Fig. 1) consists of only three parts: a rigid foam structure, a single flat sheet metal collector panel, and a transparent cover. To assemble the three pieces, first place the metal collector on the ledge which is molded into the foam structure, next place the cover which is glass or glass substitute on the molding-in ledge and apply adhesive/sealant. Since the manifolds are actually part of the collector body (Fig. 2), the units have only to be nested together with a sealant applied between collectors. This will complete the array. As can be seen this simple assembly yields itself easily to do-it-yourself.

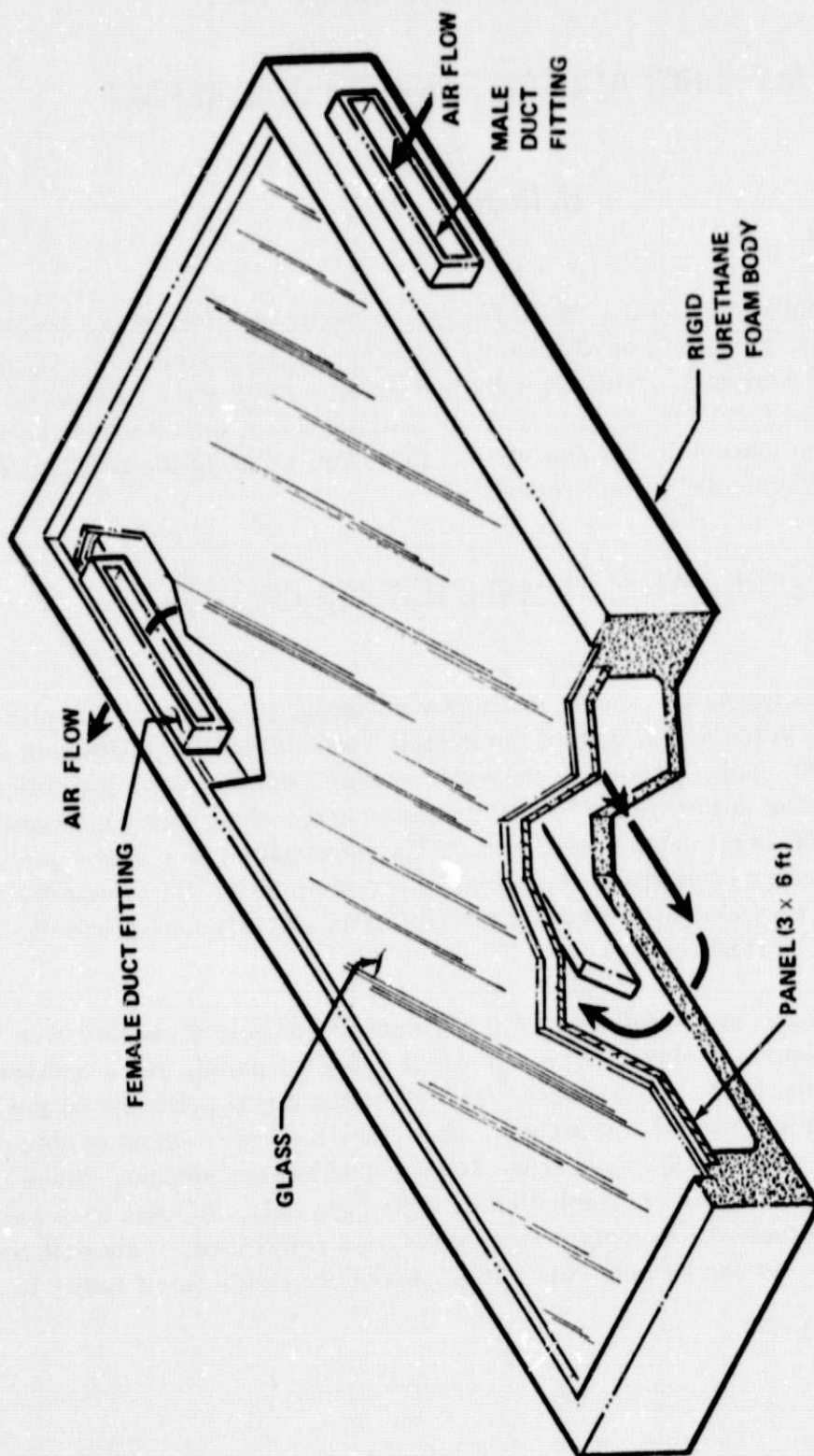


Figure 1. Hot air collector assembly.

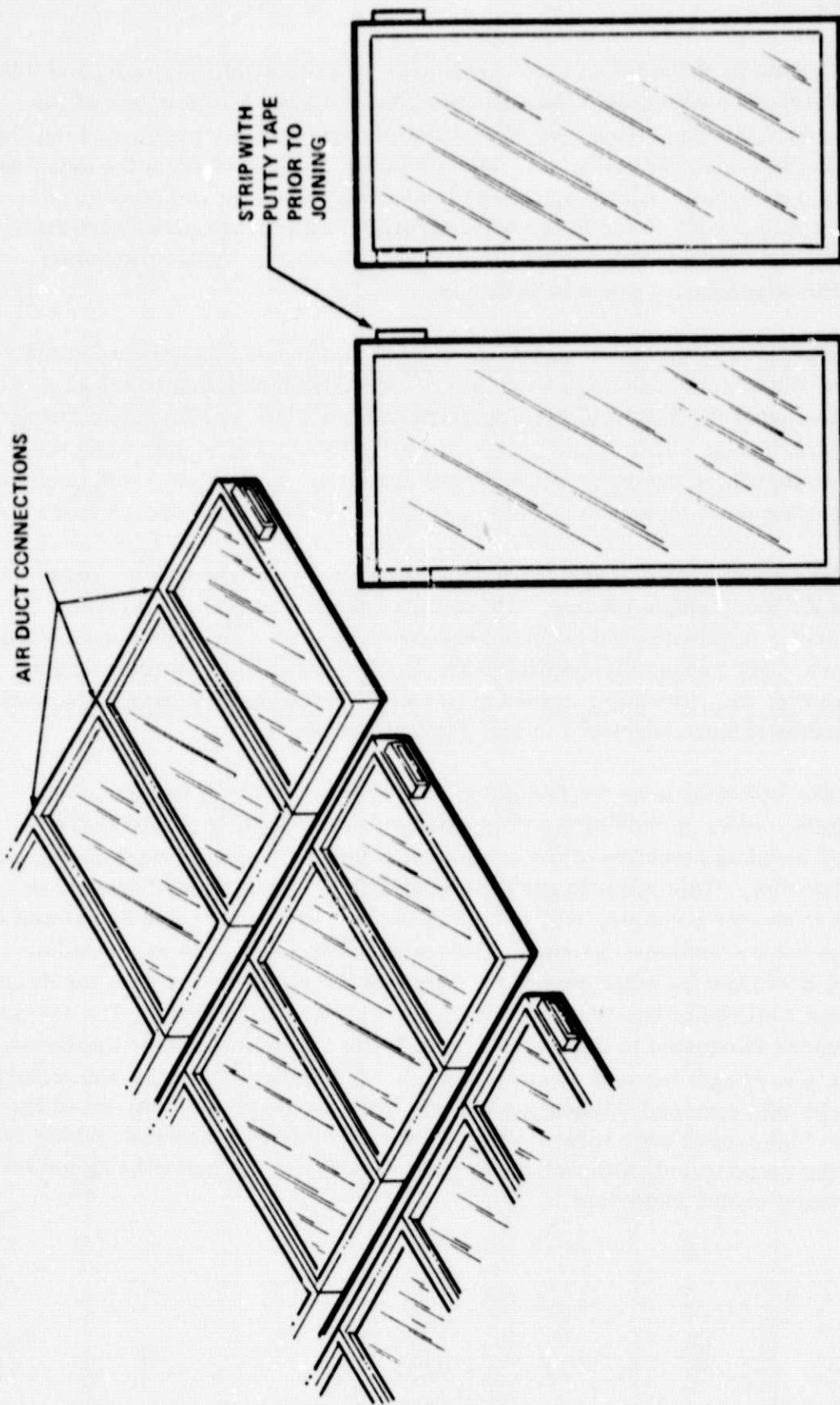


Figure 2. Hot air collector array.

Operation of the hot air solar collector is as follows: Air is forced into the collector area underneath the absorber panel; it travels the length of the panel, around the separating rib, back down the length of the panel, and out the duct fitting into the next collector. The air picks up the heat from the panel as it passes underneath. After the air passes through the required number of panels, it either goes to the house or is diverted to a storage area (such as a rock bed) and then is recirculated through the collectors. The storage bed serves the house during periods of no sun.

Another benefit can be gained by the installation of tubing between the panel and the bottom of the solar collector. With the addition of tubing in a small number of the solar collectors, sufficient hot water can be generated to supply a residence. This benefit continues all year instead of only when the heating system is in use as in conventional systems. No airflow would be necessary, as stagnation temperatures alone would be sufficient to heat the water.

The construction of the solar collector (Fig. 1) utilizing only three parts is the most unique feature. These three parts also include another feature which eliminates the requirement for connecting manifolds between the collectors. The connecting manifolds are molded into the one-piece collector housing (Fig. 2). The solar collector is much lighter than existing collectors which makes it more adaptable to existing structures.

The collector uses the insulation as a structure, the insulation, the manifolding, and a portion of the flow passage. This collector utilizes the collector panel as a portion of the structure, a portion of the flow passages, and as an absorber. This panel is not a complexly formed and welded number of parts, but merely a simple, thin flat stock sheet. The sheet could be painted or coated in the conventional manner. The transparent cover acts as a weather barrier, a window for solar radiation, a part of the structure, and as insulation. The cover could be of conventional transparent plastic or of glass. The majority of collectors fabricated to date were finished with Herculite, double thickness, which is a very safe but very heavy approach. A breakage problem was experienced with this material (Appendix) but has been resolved. In fact, all of the early problems have been solved, except the collector tray material, which is still being investigated, although acceptable results are currently being achieved with present choice materials.

HISTORY OF DEVELOPMENT

The hot air collector was conceived in March 1975. First construction was in May 1975; this first item was poured from Polyurethane with 4 lb/ft³ density. The mold was of light wood construction and was a temporary mold to check out details of molding. This first item turned out successfully; therefore, it was decided to embark on a development program. The best choice of materials at this time appeared to be of CPR 421 Urethane with an overcoat of Polyester Resin (Gel-coat). A series of tests was conducted by ET44 [1]. These tests were performance tests with differing flow rates, fluxes, panel in temperatures, etc. The results of these tests proved the necessity of a larger development program. At this time, it was deemed necessary to construct two new, stronger wooden molds. These molds were constructed, and a contract was let with Solar-Tec in Salem, Ohio, June 1976 to pour a number of collectors which were constructed and tested.

At this time, it became apparent to all concerned that not all materials were suitable for the collectors. Some materials failed stagnation testing by cracking and separation from the glass; however, some collectors did considerably better, enabling the Materials Division to recommend better choices of materials for future collectors. It was also obvious that the old wooden molds were not strong enough to provide a superior product. Consequently, a contract was let with Solar-Tec to produce a very strong Polyester-reusable mold and an additional number of collectors of the best materials choice. The plan was to use them on a demonstration site, Building 4638. The contract called for a number of collectors to be poured from different materials.

Early in the development program, it was discovered that the majority of problems would be associated with the collector tray and with the pouring and the life of the foam. However, other areas caused minor difficulties.

The need for flow turbulators under the absorber was pursued by some parties, but upon testing it was proved that no need existed. Smoke testing was performed, and efficiency tests, as well as the smoke testing, proved that no flow turbulators were necessary.

MATERIALS DEVELOPMENT HISTORY

Development Prior to October 1975

After the initial concept was completed, Materials and Processes Laboratory personnel were contacted concerning the best choices of materials of which to construct the collector tray. Their recommendation was to use pour-foam CPR-421 Urethane.

A wooden mold was constructed in the carpentry shop, and two collectors were poured from the CPR-421.

Initial stagnation testing showed that excessive distortion of the tray would occur with this material. Consequently, the tray was modified to allow initial testing by removing 1 in. of the original 2-in. ridged back and substituting a 1-in. buffer in the form of a layer of pliable felt insulation (Dynaflax RF600 refractory felt). This was done to prevent a bowing outwards, and consequent separation of the tray and glass and of the tray and collector panel. The reason for this bowing was thermal expansion differences between the interior (very hot, approximately 250° to 300°F) and the exterior (ambient temperature). The insulation was, in effect, too good.

Development from October 1975 through January 1976

The previously mentioned modification relieved the expansion problem discovered earlier and allowed thermal performance testing to be accomplished. The results of these tests are presented in the Appendix. These tests were successful in proving the concept and, thus, gave justification for the larger development which was to follow.

The use of the felt layer in the tray bottom did not jeopardize the program's initial goal of having a three-piece collector because of the materials research which was to come.

Development from January 1976 through March 1976

During this period, fabrication of low cost collectors was approved, and a search for new foams was begun. Six collector trays were approved for

construction of the original CPR-421, with a gel coat exterior to stabilize it during temperature excursions. For the first time, the panels were painted with Caldwell C1077-3.

Development from April 1976 through June 1976

The first successful collector was made from the pour-foam CPR-421; however, a lot of time-consuming hand-filling was necessary, so an investigation was conducted on other types of injection. Attempts were made to use the Texthane 333 spray foam in the spray machine in Building 4707; however, this was unsuccessful due to the machine's being set up for pour-foam. Volumetric output was marginal, leaving voids. A semi-open mold had to be used to gain access to all sections of the mold. Poor results were due to shrinkage of the foam and insufficient rise time.

The mold was then sent to the Wood Model Shop for modifications to make it a completely closed cavity except for pour holes and risers. A slower-rise pour-foam (FSC-6850) was then tried and it gave good results. The self-generated pressure distributed the foam to all parts of the mold. These collectors proved the process feasible, and CPR-421 was eliminated as a candidate material because FSC-6850 was easier to use and had higher temperature resistance.

At this time, the need for a contractor became evident. A competitive procurement was issued and, consequently, a contract was signed with Solar-Tec in Salem, Ohio. This contract was for 12 collector trays. NASA was to provide the molds, two types of high temperature pour-foam, gel coat, mold release, PVA liquid parting film, and spray.

Twelve acceptable urethane foam hot air solar collector test trays, drawing number 20M33667, were molded by Materials and Processes Laboratory and Structures and Propulsion Laboratory personnel with the assistance of Solar-Tec in Salem, Ohio. Five trays were molded using Foam System Company FSC-6850 (2-lb, 300°F material); six were molded with Olin Chemical Co. AP-3104 (4-lb, 250°F material). In addition to the 12 trays previously mentioned, many other trays were molded with the various materials but were lost due to problems with venting and ejection from the mold. Also, four trays were molded with ICI United States, Inc., polyester resin, 3M glass bubbles and Pittsburgh Corning celramic glass nodules. Two of these trays cracked severely

and were scrapped. Two trays were brought back, one with glass bubbles and polyester (cracked but repairable) and one with glass bubbles, ceramic nodules, and polyester (also cracked but repairable). During this effort, Solar-Tec was overly cooperative and supplied manpower and support services far in excess of their contractual obligations.

The Test Laboratory assembled three each of the Olin AP-3104 and the FSC-6850 test trays, plus the one Olin AP-3202 test tray with absorber panels and glass covers. The Olin trays had the absorber panel screwed to the center baffle, and the FSC trays had the absorber panel bonded to the center baffle. The Olin AP-3202 was assembled as a display part. The necessity to secure the absorber panel to the baffle became apparent when flutter developed in the three hot air collectors which were being subjected to flow tests in Building 4619. (These earlier collectors were built entirely in-house and completed July 7.)

The one main problem encountered during this fabrication effort was the inconsistent removal of parts from the wooden molds. The heat and pressure of the process allowed the urethane foam to flow into the surface of the wood or between the parts of the mold. When additional collector trays were to be made, a less porous one-piece mold is considered essential for consistent satisfactory molding. The Sekely Industrial Tool Company, the parent company of Solar-Tec, submitted quotes to build a steel mold both with an air ejection system and a polyester sand and steel mold. These molds were to be high production tools with quick opening and closing capabilities. The first molds had 40 nuts and 4 screws to be installed and removed.

A procurement request was prepared August 4, 1976, to have Solar-Tec Inc., Salem, Ohio, fabricate a new mold and 37 hot air solar collector test trays (MSFC Drawing No. 20M33699). The mold was made of sand-filled polyester with aluminum core reinforcement and had the following operational features:

- 1) Air ejection for the part
- 2) Hinged top for uniform introduction of the part material
- 3) Toggle action clamps for quick closing and opening
- 4) Sufficient strength to hold the part dimensions using a 2-lb/ft³ urethane foam packed to 8 lb/ft³

- 5) Service life sufficient to form a minimum of 300 parts
- 6) Integral cooling coils (tubes).

The final feature was used in the further development of the process to form an integral skin on the test trays. If a sufficient self-skinning process could not be achieved, then a gel coat would have to be used at additional cost.

Materials to be specified by the Materials and Processes Laboratory are as follows:

- 1) Test tray material
- 2) Gel coat
- 3) Final paint
- 4) Equipment for applying the gel coat and PVA.

Solar-Tec had just purchased a new Admiral pour-foam applicator, and it was adequate at 60 lb/min to inject the required 13 lb within the required cream time of the material. Two new wooden molds, stronger than the first, were constructed by MSFC to incorporate configuration changes and, also, changes to facilitate process development.

Development from July 1976 through September 1976

Representatives of Solar-Tec, Inc., visited MSFC, October 14, 1976, to finalize some of the details of the collector tray mold and tray configuration.

The three hot air solar collector test trays (constructed of FSC-6850), for the air flow and pressure drop tests and possibly the solar simulator temperatures cycling tests, were modified to the latest configuration, painted with white latex, and fitted with the collector panels and glass covers. This work was completed on July 1976; the trays were mounted on the three-module test frames and delivered to the Test Area on July 7.

Doubts prevailed on July 9 concerning the potential use of UpJohn CPR-474D three-part foam for the solar collector test trays to be pour-foamed at

Solar-Tec, Salem, Ohio, from July 12 through 23 with MSFC personnel assisting. The Foam System Company FSC-6850 and the 3M polyester foam were available plus two other (250°F) pour foams that Solar-Tec agreed to supply as a substitute, all within the allotted funding. With this in mind, the decision was made to drop CPR-494D from the initial contract.

Development from October 1976 through December 1976

Representatives of Solar-Tec, Inc., were at MSFC October 14, 1976, to finalize some of the details of the collector tray mold and the collector tray configuration. They also brought six 2 ft by 2 ft by 4 in. samples from their attempts to develop a process to form an integral skin using FSC-6850 and UpJohn 479 pour foam. The quality of the foam was poor due to hand mixing, but the thickness of the skin on both types of foam shows promise. If a method could be developed to form a skin on the collector trays without using a gel coat, then production time for the 37 trays would be cut almost in half with a substantial cost reduction.

The 2 1/2-month delay in initiating the contract with Solar-Tec, Inc., moved the delivery date of the finished parts to December 30, 1976. Materials and Processes Laboratory negotiations with Solar-Tec and the Procurement Office resulted in an earlier delivery date:

- 1) 6 trays — December 3, 1976
- 2) 12 trays — December 10, 1976
- 3) 19 trays — December 17, 1976.

Due to the 5-week lead time required by Foam System Company to formulate the FSC-6850, the only material to meet all the test requirements, Materials and Processes Laboratory designated the FSC-6850 as the pour-foam material for this contract to meet the delivery date. Although this material met all the test requirements, it does not have an integral skin which could be a possible requirement on any follow-on procurements.

A contract was awarded October 26 to Solar-Tec, Inc., Salem, Ohio, for the fabrication of a mold and 37 hot air solar collector trays (NAS8-32168).

During the week of November 15, samples of the three epoxy gel coats (Hysol, Furname, and Magnolia) withstood cyclic testing to 400°F for 3 days without failure. A sample was prepared with all three types on FSC-6850 pour foam (type being used at Solar-Tec for test trays). The work at Solar-Tec proceeded on schedule, including checking of the mold master for compliance with the design drawings.

By December 6, the pour-foaming operations were a week behind schedule due to start-up problems. Materials and Processes Laboratory reported that two test trays without gel coat, one completely covered with gel coat and one with gel coat on the outside only, had been fabricated. The initial quality of the trays was fair, but the bitter cold weather in the Ohio area made it difficult to heat the building adequately to permit proper thermo reactions of the foam and gel coat.

By December 15, the pour-foaming operations at Solar-Tec were approximately 2 weeks behind schedule. Although eight test trays had been received at MSFC, none were judged of acceptable quality for the Building 4638 heating system. The first four test trays were badly damaged by Emery Air Freight when shipped from Solar-Tec December 8. Four more test trays were brought back to MSFC by Materials and Processes Laboratory personnel for testing and were assembled by ET31, Fabrication Division. Three of these test trays were heat-cured by ET31 by gradually raising the temperature to 250°F while being physically restrained. The problems still persisting in the pour-foaming operation were as follows:

- 1) Air entrapment in the foam
- 2) Separation of the foam from the gel coat
- 3) Warpage of the tray after removal from the mold
- 4) Blistering of the gel coat, increased by post molding heat cure
- 5) Time required to cure the epoxy gel coat.

Representatives of Solar-Tec, were at MSFC on December 14, 1976, to help work out a plan to overcome the problems. In a joint meeting with Solar-Tec, Structures and Propulsion Laboratory personnel, and Materials and Processes Laboratory personnel, the decision was made to:

- 1) Take 1 week to modify the mold and then try several variations of the molding process.
- 2) Have Materials and Processes Laboratory Representative return to Solar-Tec December 20, 1976, to monitor this effort and add his expertise.
- 3) Slip the schedule of the complete delivery of 30 trays until January 7, 1977.
- 4) Modify the Solar-Tec contract to provide for more FSC-6850 pour foam and more gel coat and to fabricate a curing jig to hold the test trays in shape during the post molding cure cycle. Heat curing is to be at Solar-Tec.

Delivery schedule to MSFC is as follows:

2 units — December 23 — Transport by MSFC — EH43

10 units — December 30 — Transport by Solar-Tec

31 units, mold, master, and curing fixtures — January 7 — Transport by Solar Tec.

These variations and refinements in the processing, tooling, and scheduling were necessary to produce collector test trays of acceptable quality for Building 4638.

Development from January 1977 through March 1977

A "noncompetitive procurement justification" was issued January 20, 1977, for the third supplement of the contract with Solar-Tec, Salem, Ohio. This supplement calls for the evaluation of six candidate replacements for the presently used FSC-6850. According to Materials and Processes Laboratory personnel, a list of five possibilities consisted of UpJohn 474D, UpJohn 479, FSC 76-1-29S, Texas Urethane 2000-24, and Polymer Development Labs TDL 4034-2.5S. Other companies were being contacted so this did not constitute the final list.

Deveiopment from April 1977 through June 1977

A visit by Materials and Processes Laboratory Personnel was made to Solar-Tec in Salem, Ohio, during the week of March 28. Solar-Tec had started evaluating six new foam systems, one of which would be selected to manufacture additional hot air collector trays. Two of the six foam systems processed during the first week performed better from a processing standpoint than the original Foam Systems Company No. (6850). Four of the new trays from each of the six systems were delivered, two with white gel coat and two bare. Four panels fabricated from UpJohn 479-3 looked very good. The Epoxy Gel coat was cured approximately 2 1/2 hr, then the foam was poured and allowed to cure approximately 30 min. Two of the four panels were removed from the mold without using the air ejection. The release system worked out very well. Part shrinkage was measured on all panels, and the mold was reworked to allow for shrinkage so that routing would not be required prior to installing the glass and metal collector plate.

Solar-Tec, Inc., Salem, Ohio, fabricated two hot air solar collector test trays for our display purposes. These trays were received on April 11, 1977, and exhibited in Building 4711.

Materials and Processes Laboratory personnel now had four foam materials selected. A fifth foam material was a possible candidate if thermal results were satisfactory on the UpJohn CPR 479 being tested. The selected materials were from Texas Urethane, Foam Systems Corporation, and Polymer Development Corporation.

Development from July 1977 through September 1977

MSFC solar collector panels have been made from the following materials:

Foam Systems Co.	FSC 76-1-29
Polymer Development Lab, Inc.	PDL 4034-2.5s
UpJohn Company	CPR-479-3 and 479-2
Texas Urethane	Textthane 2000-24
Texas Urethane	Textthane 2002-42.

The Foam Systems Co. Foam FSC-76-1-29 has been eliminated from stagnation testing due to poor molding characteristics. An additional material, UpJohn CPR 479-2, was selected and 18 panels have been fabricated thus far. The panels were fabricated using 2-lb material (CPR 479-2) and were approximately 30 percent lighter than the 3-lb material, were easier to mold, and did not shrink on demolding as did the CPR 479-3.

As part of the evaluation of candidate pour foam materials, four more test trays poured with Texthane 2002-42 and Polymer Development Laboratory PDL 4034-2.5s (one each gel coated and one each bare) were given to Structures and Propulsion Laboratory for outdoor testing at Building 4638. The PDL was the first material in this evaluation that did not exhibit any shrinking problems.

The evaluation test collector made with UpJohn 479-3 was shipped back to Solar-Tec. This collector had been subjected to outdoor stagnation testing and was used to determine the extent of mold modification. The fifth batch of candidate pour foam test trays (these are made with Texthane 2000-24 pour foam) was received.

The mold was repoured the week of September 12 and then seasoned by pouring 12 test trays using UpJohn 479-2 the week of September 19.

Development from October 1977 through December 1977

The last four solar collector test trays were received from Solar-Tec, Inc., Salem, Ohio, on the Contract (NAS8-32168) to evaluate six candidate pour foam materials. The trays were poured with UpJohn 479-2. One tray was submitted to EH33 for material evaluation, and two were submitted to EP12/Structural Concepts Branch for assembly and testing in actual use conditions.

A meeting was held November 4 with representatives from Science and Engineering SHAC and Test Laboratory to get the hot air solar collector system in Building 4638 operational by November 9. Six collectors had been lost due to glass breakage, so it was decided to use the gel-coated trays produced in the evaluation of candidate pour-foam materials contract (Solar-Tec, Salem, Ohio) to quickly assemble the needed replacements. Using the gel-coated trays eliminated time delays for cleaning and painting. Eight trays were furnished that had been made from PDL 4034-2.5S, Texas 2000-24, Texas 2002-42 and

CPR 479-2, all coated with white epoxy gel coat. The Hot Air Solar Collector System on Building 4638 was now operational but still had some facility problems. The eight replacement collectors were installed without problems. Refurbishment work was done on some of the collector trays that were showing the effects of a summer of stagnation temperatures.

The Test Laboratory had assembled 18 new collectors, these were pour-foamed with UpJohn 479-2 in the modified mold at Solar-Tec. The major problem was the removal of the mold release to assure a good bond for the painting and the RTV140 sealing of the glass glazing. This problem was worked the week of October 18, and the latex house paint designated for use on the interior and exterior surfaces of the trays was checked out with the Sherwin-Williams technical laboratory in Atlanta relative to outgassing characteristics. A cleaning process was developed to prepare the collector test trays for painting. The cleaning procedure developed consists of a 10-minute treatment with a polyurethane stripper (Turco 6015) followed by a wash sequence with a Selig cleaner utilizing a steam cleaning "Jenny." The trays were dried, after the wash, at 150°F for 1 hr in a forced air oven, lightly hand-sanded, and then painted with Sherwin-Williams A-100 latex paint. These collectors were stored in the Valve Clinic, awaiting the funding of the facility contract for their installation.

The mold and master made and used at Solar-Tec (Contract 32168) were received here at MSFC and put in storage.

PROGRAM SUMMARY THROUGH JUNE 1978

Final conclusions are not possible at this point, but a brief status type evaluation is made. The FSC 6850 isocyanate foam from Foam Systems Company was brittle and developed cracks and warpage under the initial stagnation heating. Six of the original thirty-two collectors made with FSC 6850 have now endured 1 1/2 years of stagnation testing on Building 4638. Their condition has stabilized, but they should be replaced.

The four foam types (two collectors each) installed on Building 4638 in November 1977, which resulted from the contract extension to evaluate six candidate materials, are also still undergoing stagnation testing. Cracking of the gel coat has occurred in some places, but overall condition is still good. These four foams were Polymer Development Laboratories PDL 4034-2. 5S

Texas Urethane 2000-24 and 2002-42, and UpJohn CPR 479-2; all were coated with Hysol high temperature gel coat and then painted white with Solar-Tec epoxy. Their performance is much better than the FSC 6850 at this point in testing.

The developmental paint, Caldwell Ci077-3/66, used on this program as the baseline absorber coating has had some adhesion problems after a year of stagnation temperatures. This paint was applied over a chromate conversion coated aluminum surface, and it can now be seen that a primer was needed for more consistent results.

Dow Corning DC 140 and DC 731 were used to seal the glass to the foam collector tray, these materials give good results if the surfaces are cleaned properly. There are still problems in this area.

Herculite glass was used in these collectors, and the early problems with breakage was attributed to:

- 1) Scratches induced by improper handling during installation
- 2) Heat-caused warpage and distortion of early collector trays
- 3) East-West orientation of the longitudinal dimension of the collector which places the hot and cool edges of the glass closer together to induce steeped thermal gradients. Most of the breakage occurred on cool mornings a few minutes after sunrise. Glass breakage is no longer causing a problem.

The transparent cover could be of any suitable, long-life material such as Lexan, Kalwall, etc. Choice of material would be predicated by cost, weight, and other considerations according to application.

The collector panel can be of any suitable metal; however, aluminum has been used throughout this program. Availability would predicate this choice also.

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TEST REPORT – PERFORMANCE TESTING OF MSFC LOW COST AIR COOLED SOLAR COLLECTOR

INTRODUCTION

As requested in Memorandum EP12 (75-49), an MSFC designed low cost flat plate Hot Air Solar Collector was tested for thermal performance and for structural integrity at stagnation temperatures. The EP12 designed and ET31 constructed air collector was tested South of Building 4620 during the period from October 30, 1975, to November 5, 1975. The air collector was designed with low cost as the prime consideration. Material costs for this panel are estimated to be less than \$.80/ft². Performance of this low cost solar collector is described herein.

TEST HARDWARE AND INSTRUMENTATION

The EP12 air collector housing was formed of CPR 421 Urethane foam with an overcoat of polyester resin (Gel-Coat). The original design was modified by reducing the rigid foam thickness of the back of the housing from 2 in. to 1 in. and substituting a 1 in. layer of pliable felt insulation (Dynaflex RF600 Refractory Felt). This modification was intended to relieve the problems associated with dimensional changes caused by temperature differentials in the foam material. The collector absorber panel consisted of a thin flat sheet of aluminum coated with Caldwell C1077-3 (T-Model Black). The collector was glazed with a single layer of standard window glass. The hot air collector assembly is described in MSFC Drawing 20M33671.

The hot air collector was instrumented and installed in the test setup described in Figure A-1. The test article was inclined at 45 degrees and oriented to the south behind Building 4620. Air was heated to the prescribed test temperature and was flowed through the collector in a U-shaped path as shown in the test schematic. Volumetric air flow was measured with a turbine-type flowmeter to ± 1.2 ACFM. This volumetric flowrate was later corrected

for temperature and pressure at the flowmeter to give mass flow. Pressures were very nearly ambient downstream of the throttle valve and were measured to ± 0.05 in. of water with a simple water manometer. Temperature measurements were made with copper constantan thermocouples to $\pm 1^\circ\text{F}$. Solar flux is the component normal to the panel and was measured with an Eppley Black and White Pyranometer Mod. 8-48. Data were recorded at 2-min intervals using a Hewlett-Packard Digital Data Acquisition System and printed out on teletype.

TEST DESCRIPTION

The air collector was installed as shown in Figure A-1. The panel was inclined at 45 degrees and oriented to the south. An air flow was initiated using the test setup as shown. The heater power was adjusted to give the proper test temperature at the panel inlet. The solar collector cover was removed to permit sunlight to strike the panel, and the system was allowed to come to equilibrium. Air mass flow, temperature rise across the panel, and solar flux were recorded. Collector power and efficiency were calculated. The panel was mapped over a range of inlet temperatures (55.0° to 204.7°F) and flows (16.3 to 163.7 SCFM). Stagnation tests were performed by shutting off the panel air flow and allowing the panel to come to thermal equilibrium with its environment. During stagnation testing, the collector structure was observed for cracks and dimensional changes which might be caused by thermal expansion of the foam material. Data from these tests are presented in Table A-1.

ANALYSIS AND CONCLUSION

Air collector performance was mapped over a range of air flowrates, inlet temperatures, and solar flux. These data are presented in Figures A-2, A-3, and A-4 and in Table A-1. Efficiencies are actual measured ratios of captured energy to incident energy. Figure A-2 presents a performance map of unreduced data corrected only for instrumentation errors. It should be remembered that these data are good only for the environment seen by the collector on the days tested. Solar flux for these data ranged from 263 to 330 Btu/hr-ft² and ambient temperature varied from 63° to 83°F . Wind is neglected in this consideration but should be minimal due to the shielding given by structures adjacent to the test setup. Wind values from the solar house roof are

available but are not directly applicable. A crude attempt at data reduction is presented in Figures A-3 and A-4. A coarse description of collector performance is given in the following equation:

$$\eta = \alpha\tau - U_L (\hat{T}_{\text{panel}} - T_{\text{amb}}) / Q_1 \quad (\text{A-1})$$

where

η = Collector efficiency

α = Plate absorptivity

τ = Transmittance of the glass cover

U_L = Overall heat loss coefficient

Q_1 = Solar flux

\hat{T}_{panel} = Average absorber plate temperature

T_{amb} = Ambient air temperature

Another commonly used equation relates the collector efficiency to the average fluid temperature (\hat{T}_{air}) with the inclusion of a plate efficiency factor (F) which accounts for the heat transfer from the plate to the working fluid. This relation is given by the following expression:

$$\eta = F[\alpha\tau - U_L (\hat{T}_{\text{air}} - T_{\text{amb}}) / Q] \quad (\text{A-2})$$

If one considers all of the terms in equations (A-1) and (A-2) to be constants with the exception of efficiency and temperatures, the equations become linear and yield straight line plots. These equations are drawn in Figures A-3 and A-4 as straight lines through points calculated from real test data. As seen from these plots, the fit between theory and real data is rather poor. Figure A-4 displays data which are fairly closely grouped but which has questionable linearity. Figure A-3 displays considerable scatter among the data. The reason for this is that the heat loss coefficient U_L and efficiency factor F assumed constant in equations (A-1) and (A-2) are not really constants, but are highly dependent on temperature and air velocity.

This theory is therefore not sufficiently developed in this simple form to adequately describe solar collector performance, particularly over a wide range of environment. Figures A-3 and A-4 are presented only as a rough comparison between the MSFC air collector and other collectors which have been described in this manner. Performance of a typical similarly configured flat plate water cooled collector is overlayed in Figure A-3. This plot indicates that the water cooled collector is more efficient than the air cooled collector by a factor which varies with operating temperature. Given the relative costs of the MSFC air collector and the cheapest water collectors, however, the air collector appears to be a very cost effective means of collecting solar energy particularly at lower operating temperatures.

Stagnation testing failed to produce any measurable dimensional changes in the collector housing. Several cracks were observed in the Gel-Coat coating and are thought to be associated with the mechanical stress of handling the collector.

Any questions or comments concerning this test should be directed to J. C. Reily, 453-3378.

TABLE A-1. CORRECTED DATA AIR COLLECTOR TEST

Time CST	T1 Inlet Air (°F)	T2 Outlet Air (°F)	T5 Panel In (°F)	T6 Panel Out (°F)	T8 Ambient Air (°F)	F1 Air Flow SCFM	Q51 Solar FWX (Btu/hr-ft ²)	P1A Collector Power (Btu/hr)	P6A Incident Power (Btu/hr)	A1A Collector Efficiency (%)
October 30, 1975, Performance Test										
10:22	98.9	157.9	175.3	208.8	60.1	19.0	285.0	1234	4770	25.9
11:06	100.3	148.4	169.5	204.5	63.4	33.7	297.0	1783	4972	35.9
11:32	100.3	133.4	152.2	185.0	64.7	65.3	300.1	2378	5024	47.3
12:20	142.1	163.8	181.6	204.9	65.9	59.8	291.8	1426	4885	29.2
12:44	139.5	171.3	190.8	213.0	66.9	30.3	282.8	1062	4734	22.4
13:20	140.5	175.0	193.3	212.0	67.0	16.3	262.9	619	4400	14.1
Stagnation Test										
13:24	152.6	131.8	198.4	210.4	68.1	0	260.6	0	0	0
13:40	167.4	140.0	207.6	204.7	67.2	0	248.0	0	0	0
October 31, 1975, Performance Test										
10:36	55.1	100.2	129.4	166.8	62.8	56.4	294.0	2806	4921	57.0
10:54	55.0	76.6	102.2	122.1	65.6	163.7	296.9	3821	4969	76.9
11:06	80.6	99.1	122.7	139.5	64.2	157.2	299.0	3135	5006	62.6
11:20	80.8	107.4	130.5	158.0	65.2	102.6	302.6	2949	5066	58.2
11:38	79.2	122.9	150.9	185.0	64.9	48.3	308.5	2281	5164	44.2
12:12	180.3	190.4	202.1	217.4	66.6	51.6	280.0	565	4688	12.1
November 3, 1975, Performance Test										
11:05	179.0	206.6	220.6	243.2	76.3	28.8	330.7	865	5536	15.6
11:14	204.7	215.5	228.1	245.1	78.5	78.6	298.2	942	4992	18.9
11:50	179.3	189.6	200.2	217.3	78.9	101.7	302.8	1136	5069	22.4
12:12	160.2	174.9	186.5	208.5	80.4	89.1	292.6	1567	4898	32.0
13:02	159.1	180.1	194.5	214.6	78.6	45.0	272.8	1023	4568	22.4
13:20	158.8	188.1	203.0	225.2	81.6	27.4	274.0	869	4588	18.9

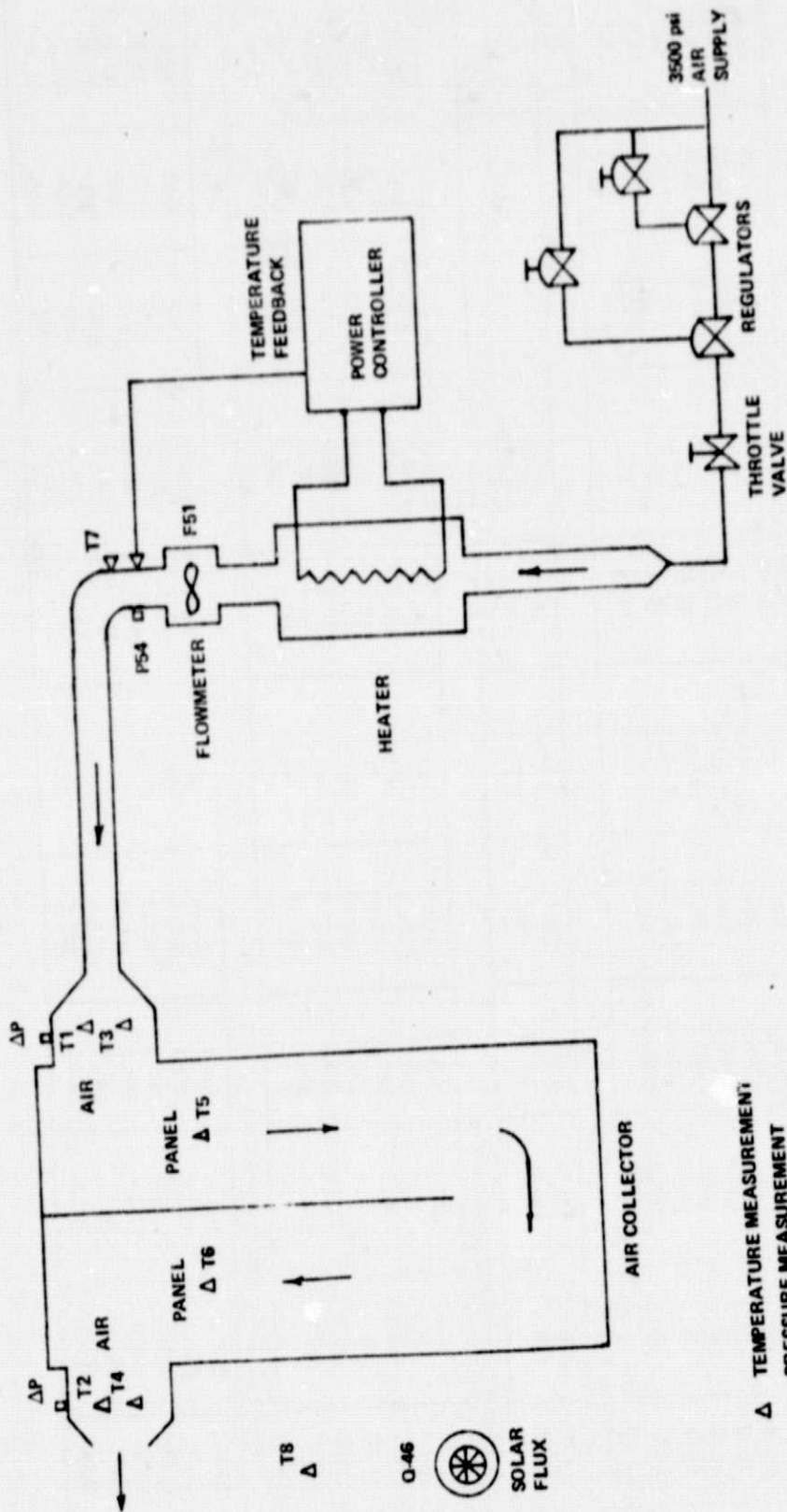


Figure A-1. Test setup — hot air solar collector.

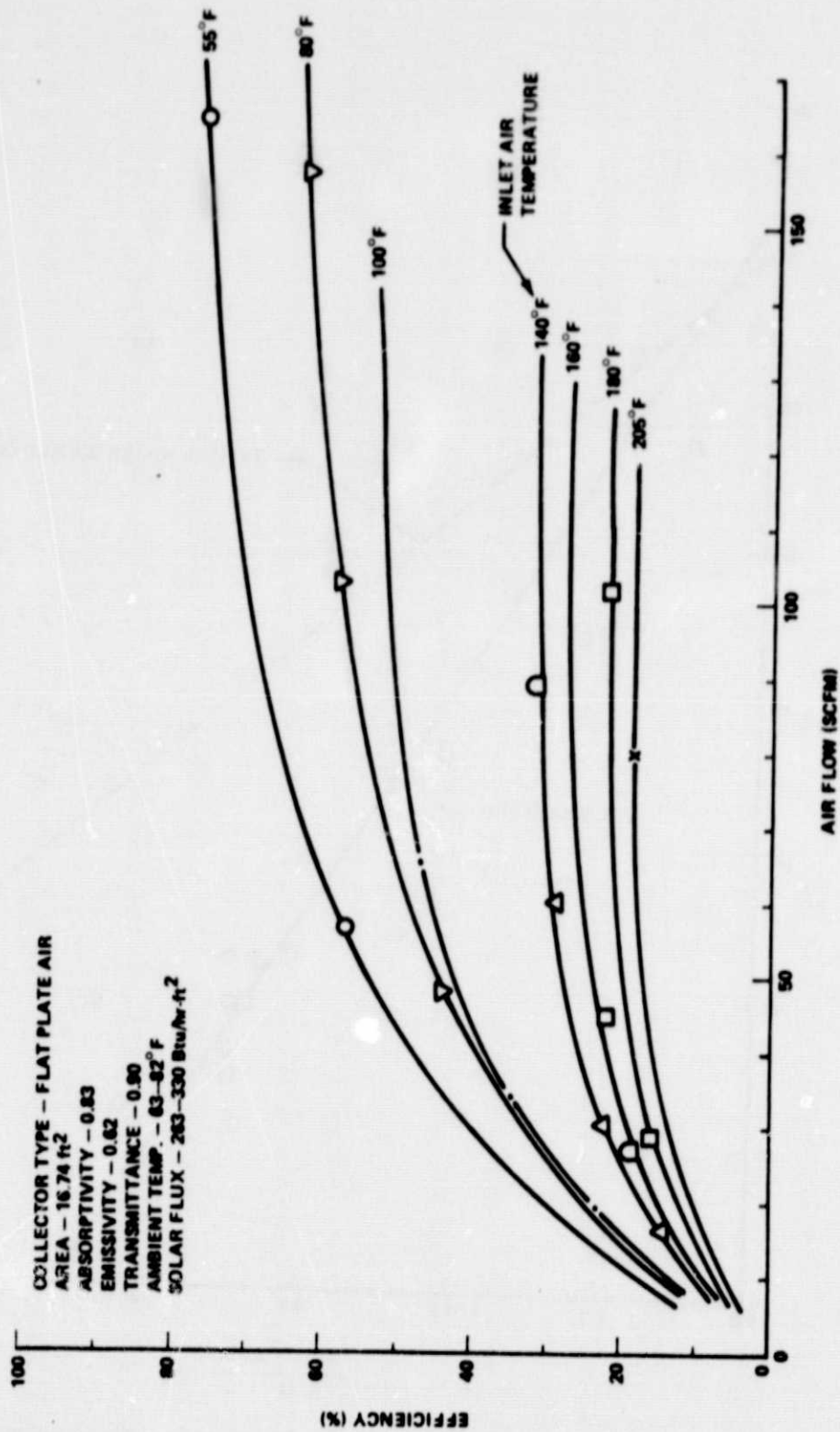


Figure A-2. Air collector performance data collected in ambient environment under actual sunlight.

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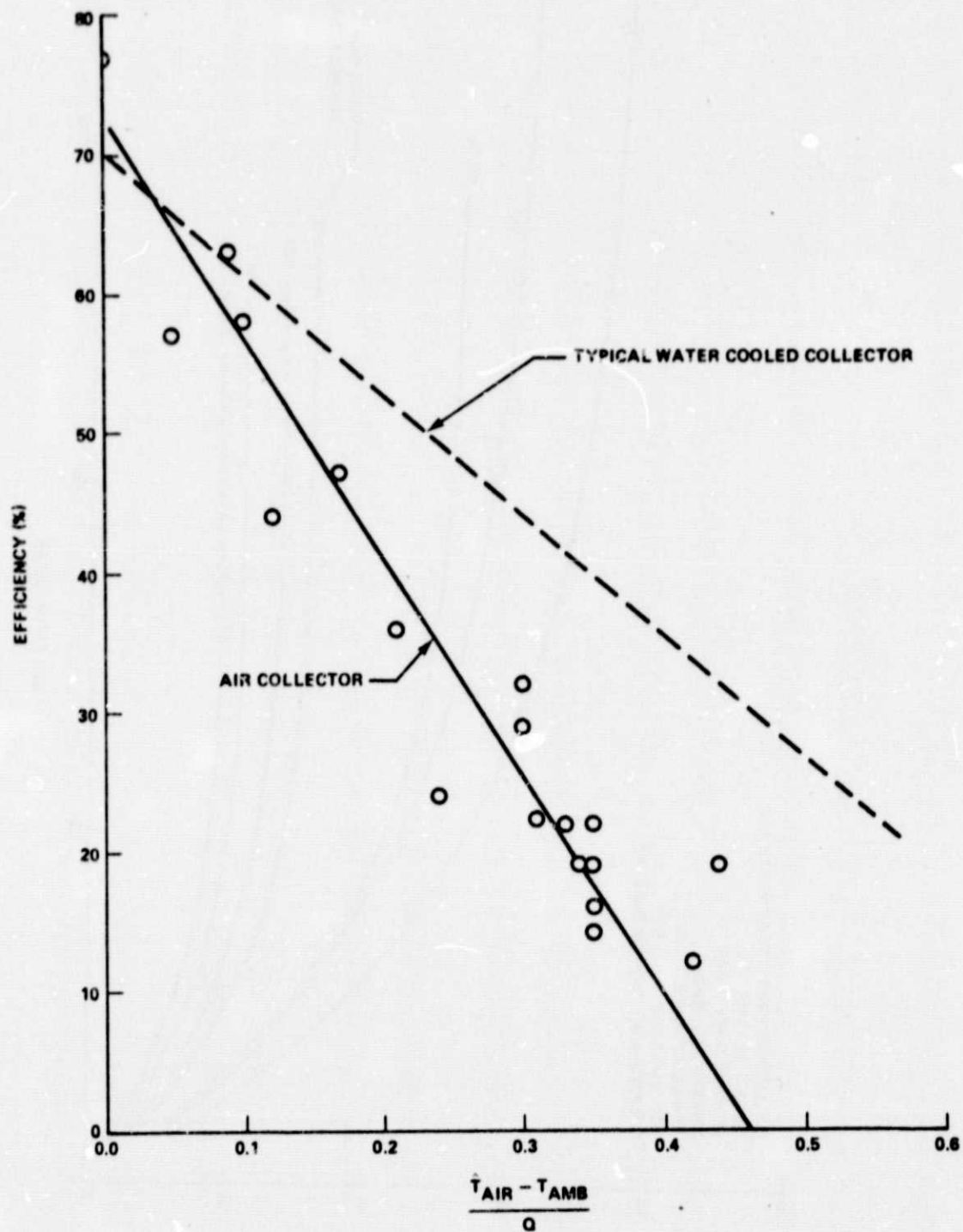


Figure A-3. Air collector performance as a function of the average air temperature.

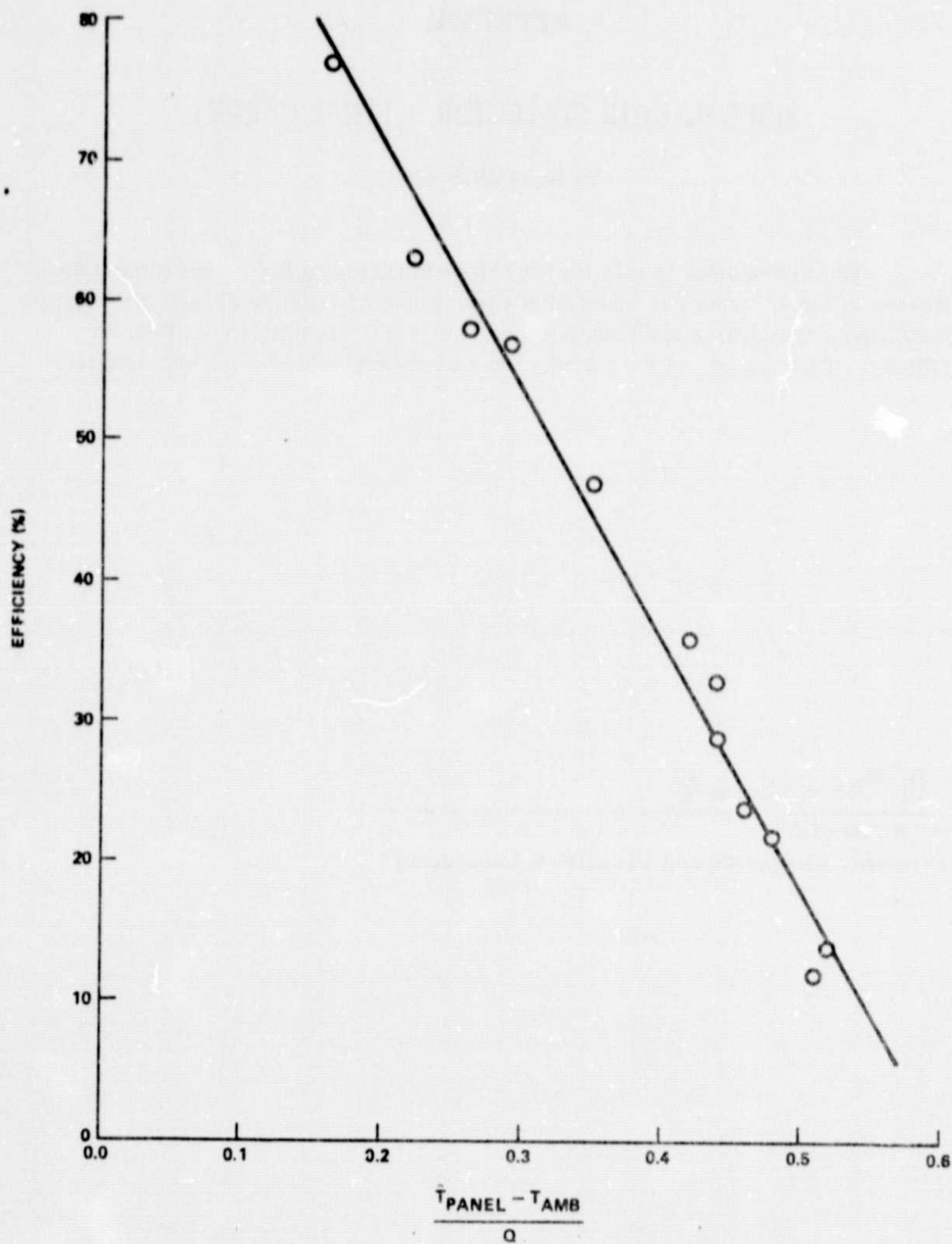


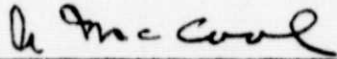
Figure A-4. Air collector performance as a function of the average panel temperature.

APPROVAL

MSFC HOT AIR COLLECTOR — FINAL REPORT

By Kenneth Anthony

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.



A. A. McCOOL

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